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ADVANCED RESEARCH AND TECHNOLOGY

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The primary role of the Office of Advanced Research and Technology in NASA is to provide the technology needed for future aeronautical and space systems. This gives the Nation maximum flexibility not only in choosing specific national objectives in air transportation or space exploration but also in choosing the best and most economical systems for meeting these objectives.

A secondary but vital role is to assist others on problems where we have competence. By "we" I mean the government - university - industry teams that work together on the research tasks that make up our program. By "others" I mean 1) other NASA offices with responsibility to develop and operate space flight equipment, 2) other government agencies such as the Departments of Defense, Transportation, Commerce, and Health, Education and Welfare, and 3) industry such as those who wish to make use of our unique facilities or our technology to solve a problem or to develop new capability.

A third role of OART, which follows from the activities of the first two, is the advancement of knowledge in physical and life sciences that is useful in many fields beyond aeronautics and space.

Figure 1 shows the elements of the program grouped as aircraft and space technology and technology basic to both. In aircraft technology, we conduct research on the various engineering disciplines and on problems related to classes of aircraft. I will return to these in a few minutes. In a similar manner, space technology covers pertinent engineering disciplines and systems applicable to launch vehicles and spacecraft for classes of missions. The technology basic to both aeronautics and space involves human factors, electronics, materials, and physics.

In FY 69, the R&D program for research and technology is 285 million dollars. Of this, about one third is aircraft technology and related research and two thirds space technology. About sixty percent of the program is carried out by industry, ten percent by universities and non-profit institutions and the remainder in-house.

I want to discuss three major needs, which can have important implications in future aerospace trends, and what we are doing about them.

The first of these is the need for increased aeronautical research. The aircraft technology portion of our program goes back 53 years when the National Advisory Committee for Aeronautics was formed to conduct research on the problems of flight with a view towards their practical solution. When NASA inherited the 300 million dollar NACA research plant and staff of some 8,000 people in 1958, it also inherited an international reputation for excellence in aeronautical research. During the early years of the space program, much of this NACA talent was diverted from aeronautics to the rapidly developing space program and as a result the amount of aeronautical research went down sharply. The problem was recognized several years ago and since then we have been slowly but steadily building up the aeronautical portion of the NASA program with excellent support from Congress and others.

In FY 1961, for example, most of the aeronautical research was done in-house with less than a million dollars in R&D funds. By FY 1967 this had risen to 35 million dollars and this year it is 95 million dollars with industry carrying out the major part of the program. We are doing all we can to keep the aeronautics program growing in a sound and orderly fashion because there is much more that needs to be done. We also see an even higher share of the funding going to industry for reasons I will bring out later.

A large portion of the aeronautics program continues the NACA role of research and support to the aircraft industry and to the military but with emphasis on civil transportation.

In research, we are applying modern analytic and experimental techniques to obtain new information in the older aeronautical sciences.

Take aerodynamics research for example. The simpler, first order aerodynamic characteristics of this oldest of aeronautical disciplines are well understood and amply documented.

As aircraft become more complex and their performance and range increases, however, second and third order aerodynamic effects, which are not well understood, become critical to the success or failure of the design. This need, coupled with the modern computer, has stimulated research on complex problems such as boundary layer growth, transition, and separation and the determination of drag, lift, and moment values over a range of speeds.

This type of work is just beginning as we seek to bridge the gap between it and the older, empirical techniques. An illustration of recent aerodynamic research, where we are attempting to combine the old and new approach, is shown by Figure 2. We have been working of airfoils for subsonic transports for several years to find ways of preventing a sharp increase in drag as high subsonic speeds are approached. The increase in drag is caused by a shock-induced air separation on the upper surface of the airfoil normally occurring at the point labeled "shock position 1."

Judicious shaping of the airfoil and using a slot at the rear of the airfoil proved effective in moving the shock back to the position labeled "shock position 2" and this resulted in an 18 percent increase in speed before encountering high drag. While this improvement was worthwhile, we were not satisfied because the slot adds weight, structural complexity, and fabrication costs. We continued the research to better understand the aerodynamics involved and found that we could eliminate the slot and its complexity. An unslotted airfoil is also shown schematically and it is almost as effective as the slotted airfoil in allowable speed increase before high drag occurs. The new supercritical wing permits thicker wing sections without increasing cruise drag over that of former designs. This means a higher lift-drag ratio and increases in payload and range and hence earning power of the aircraft. We plan to apply these results to military aircraft also and believe that through analytic techniques still more gains in aerodynamic design are possible.

Another venerable aeronautical discipline is loads and structures. We are developing methods of predicting loads induced by unsteady flight resulting from rough air and pilot input and means for alleviating these through automatic flight controls. We are also developing design procedures for use of new materials including composite materials and metal-composite combinations.

An interesting new result in loads and structures research is the use of a tape impregnated with boron fibers as a structural strengthening technique. Considerable work is being performed by industry and by other Government agencies, particularly the Department of Defense, on boron fibers and structures containing boron. Boron tape is a new development with some exciting new possibilities. Figure 3 compares relative weight ratios between aluminum with and without the boron tape for the same loading, 4700 pounds. Dimensions and weights of the two samples shown. The aluminum tube with boron tape weighs less than half the all-aluminum tube for the same strength. On the left of the figure is a comparison of the relative weight to strength ratios for the two samples. The boron tape, which resembles ordinary recording tape in appearance, uses epoxy to embed the boron fibers. It is applied to the metal surface with epoxy cement.

Figure 4 illustrates the calculated potential weight savings in a typical aircraft structure. Shown on the left is a panel reinforced with Z-section stiffeners made of aluminum, typical of today's aircraft construction practice. The panel would weigh 5.69 pounds and would sustain 46,000-pounds compressive load applied at the edges in the lengthwise direction. The sketch on the right shows a panel of the same length and width as the panel of the left designed to sustain the same compressive load - 46,000 pounds. The panel on the right, however, would have boron tape applied to one surface of the Z-section stiffeners which would allow considerable reduction in the size of the stiffeners. The thickness of the plate was kept the same in both cases. The reduction in the size of the stiffeners resulted in a calculated weight reduction of 24% for the structure on the right.

The design principle being pursued in this work is the application of the high-strength boron fibers at the location of maximum stress in the structure, thus using the material in the most efficient manner and reducing costs. We are presently evaluating replies from industry in response to our request for proposals for ways of best utilizing this structural concept.

In addition to applying new techniques in older disciplines, we are expanding our program in the newer sciences of importance to the advancement of aeronautics such as avionics, human factors, flight dynamics and operational environment. Let me illustrate these with one example: aircrew performance.

We know, of course, that aircrew performance deteriorates with fatigue. There are many stress factors that reduce man's physiological and psychological fitness for sustained flying. We are studying what stresses contribute to the total effect of fatigue and developing methods for measuring fatigue. It is obvious that such research can have widespread implications in civilian life, industry, the military, and space flight for situations where man must perform under high stress.

One new instrument for monitoring the heart has been developed by the Flight Research Center and is illustrated by Figure 5. It is an elastic, vest like garment which contains dry silver-coated electrodes. The vest simply holds the dry electrodes against the skin to pick up the electrocardiogram which allows the heart's electrical output to be studied in three dimensions. The vest is easily donned and is comfortable for wearing for long periods.

In other research, aircrew performance is studied to reduce the workload - particularly during landing such as a Category II condition or a minimum ceiling of 100 feet and a runway visual slant range of about 1,250 feet. At normal approach speeds and glide angles the crew has about 10 seconds after visual contact to judge whether or not it is safe to land. The Ames Research Center has adapted a flight simulator to study this workload problem illustrated by Figure 6. The degrees of physiological stress experienced by pilots in such situations is being determined by measuring the amount of stress hormones in their blood and urine. There are other related studies under way but these are illustrative of the group.

The second major part of aircraft technology deals with the problems of aircraft classes, as illustrated by Figure 7. We see an increasing potential of all these classes. We are giving more attention to general aviation and the problems of the private pilot, particularly in the areas of safety and ease of operation. As you well know, there are over a 100 thousand of these aircraft today and this number is expected to double in ten years.

For example, in cooperation with the FAA, we are working on warning indicators as a means for avoiding air collisions. One possible method for clear weather condition is the use of xenon flashing lights and electronic detectors. The lights not only give a brillian visual flash but also emit a large amount of infrared energy. The latter can be picked up by an infrared detector and used to alert the pilot who can then visually sight the other aircraft and avoid a collision. Figure 8 shows an experiment of this concept conducted by the Electronics Research Center. The Xenon light is shown mounted on the aircraft in the lower left. The detector in the bottom center was on the ground. The results, shown on the bottom right, indicate that the technique is feasible.

Perhaps the greatest future potential in aviation, however, is the short-haul market using VTOL or STOL aircraft. We are stepping up our pace of work on these type aircraft with the emphasis on making them more economically feasible and capable of all-weather operation. As you are aware, the rate of development of operational V/STOL aircraft, with the exception of helicopters, has been disappointing.

Some years ago we thought the gas turbine would provide the answer and many different types of V/STOL aircraft were build to prove it. The reasons for the failure of the development of V/STOL aircraft, despite the obvious civil and military needs, are becoming increasingly evident. One problem is illustrated by Figure 9, which shows the trade off between hover time, needed for maneuvering around crowded airports, and cruise speed, needed for good economy. No single VTOL type meets both of these performance requirements for economical operation. Another problem is the ability to take off quickly, quietly, and precisely with great regularity from small airports in all types of weather. This involves problems of flight dynamics, navigation, and terminal guidance. Here is where avionics will play an increasingly important role. Another problem is the transition between forward motion and lift which must be done efficiently and smoothly under well-controlled conditions.

We are working on these problems and virtually all the VTOL aircraft shown. Typical tasks include the jet flap rotor to increase helicopter speed and reduce vibration, the dynamics of stowed rotor helicopters, wind tunnel tests of the tilt rotor type, flight standards using the XC-142 tilt wing, and lift-fan technology using the XV-5 in cooperation with the Army.

Our work in supersonic transports is directed primarily at propulsion and flight dynamics of second-generation transports and to give technical support to the FAA in the development of the SST when needed. We are continuing, but at a reduced level, our research on hypersonic type aircraft for the distant future. The work is directed towards the practicality of cruise speeds of Mach

6 to 12 with emphasis on propulsion, structures, and aerodynamics.

One significant trend in our aircraft technology program, one that carries us beyond the role of the old NACA, is into proof-of-concept activities. Civil aviation has historically received the fruits of military aviation R&D but in recent years these benefits have been decreasing. This comes from an increasing divergence between military and civil aircraft requirements. This divergence is opening a gap between research and prototype flight equipment or aircraft and we are moving to fill this gap. Noise is a typical example of this military-civil divergence. The military places little or no emphasis on noise reduction if there is any potential performance penalty involved. As a result, most engines today, which are descendents of military developments, are quite noisy. The public outcry over aircraft noise has resulted in a step into the realm of proof-of-concept in noise research.

We are working on three approaches to alleviating or reducing noise from aircraft. The first and short range solution is to suppress the noise generated by current engines by use of acoustic absorption methods. Our first objective is to achieve a 6 to 10 PNdb reduction in fan-compressor noise during the landing approach by the modification of the nacelles of existing jet transports. The work is being performed under contract to both McDonnell-Douglas and Boeing. In the McDonnell-Douglas program, we have completed the evaluation of acoustical materials, fan exhaust and inlet design studies and duct model tests and full-scale boilerplate ground tests. The next stage will be a flight demonstration of a DC-8 equipped with modified noise suppressing nacelle to be completed by March of next year. The Boeing program, in addition to acoustic treatment of the nacelle, is also investigating the use of inlet choking by modification of the inlet geometry in flight to prevent the noise generated by the fan-compressor from propagating forward. Here we have also completed material evaluations, conducted full-scale duct tests and inlet design studies choked inlet tests and boilerplate inlet and duct tests with prototype nacelle. The next stage will be the fabrication of modified nacelles and flight tests with four modified nacelles on a Boeing 707-320C airplane to be completed by July 1969. The results of both programs will be completely documented by next fall. While these programs are not scheduled for completion for over a year the results have been disseminated throughout the industry as rapidly as they become available.

Some very encouraging results have been obtained in the program, as illustrated by Figure 10. Shown, is sound pressure level in decibels versus frequency in cycles per second for a JT3D engine currently in use on 707 aircraft. The solid curve is for the 707 production nacelle with a short fan-discharge duct. When an acoustically treated duct discharge 3/4th length of the nacelle is used, significant reduction in sound pressure level is obtained in the frequency bands in which the ear is particularly sensitive.

A second way to reduce noise is to use a steeper glide slope for landing and take-off. In tests we obtained reductions in peak ground noise of 8 PNdb by increasing the landing glide slope from 3 to 6 degrees with the decrease coming both from distance and power reduction effects. Our flight tests have been directed toward the additional guidance and control aids needed to fly the steep path. As part of this program a new flap system was installed on a Boeing 707 prototype by the Ames Research Center. Figure 11 illustrates the direct lift control devices. We are also studying pilot workload and the information he will need for utilizing steep approach paths.

The third approach to reducing noise is to design an engine from the start that will be quieter than current engines. It is this approach that leads to proof-of-concept later. The first step, nearing completion, includes engine-cycle analysis and preliminary design analyses to arrive at designs that minimize noise and retain reasonable efficiency.

The engine will have a high by-pass ratio to reduce exhaust noise. Reduction in fan tip speed appears to offer the greatest potential for reducing fan noise. The attainment of efficient fan performance at reduced speeds, however, is a problem receiving considerable attention. A requests for proposals has been issued to industry for detailed design, fabrication, and tests of a research engine. The ultimate goal is a demonstrator engine that will incorporate the best noise reduction techniques and be 20 db quieter than comparable engines in the 20,000 pound thrust class.

I mentioned earlier that in the past most new aircraft technology evolved from military requirements which bore most of the costs between technology and application. Commercial aviation could adopt the new technology at small risk and cost. But as I also mentioned previously, the noise problem is of small concern to the military so the cost of solving it will have to be shared by the industry. The cost will be very high as thousands of engines are involved. Moreover, if a proposed solution proved to be unacceptable, the costs could be disastrous to the industry. The problem also involves land use, aircraft operational control, and regulations, which are all beyond industry responsibility. In view of the national importance of this problem it seems reasonable that the government take the initiative, which it has, and that NASA should be responsible for providing the needed technology and proving its validity. It is this type of activity, proof-of-concept, that I had in mind earlier in pointing out a trend towards industry carrying an increased portion of our program.

Summing up for aircraft technology, we are increasing our effort by increases in old and new aeronautical disciplines, in V/STOL technology, and in noise reduction. The last is carrying us into proof-of-concept activities to fill a need formerly fulfilled by military R&D and this will lead to increased participation by industry in our program.

The second major need that will influence future aerospace activities is low-cost space boosters. We have seven reliable launch vehicles for space ranging from the all-solid propellant Scout, which carries about 300 pounds into orbit for a little over a million dollars, to the mighty Saturn V which will carry almost a thousand times more payload at a cost that can approach 200 times as much. These vehicles drew on the great military missile R&D of the 1950's plus other technology, such as the hydrogen-oxygen technology of the NASA Lewis Research Center developed during the same period. These launch vehicles, backed by competent teams from government and industry, have reached or are nearing a state of high reliability; they are examples of a national capability of which we can all be very proud. However, we are faced with an urgent problem - the mounting cost of these boosters. The pressing need is for boosters as reliable as those we now have but which can carry their payloads at a fraction of present costs. This means a fresh approach to the entire concept of boosters and a critical examination of each step in the complex process from the drawing board to the end of the boost operation. It would be ideal, of course, to have reusable boosters that could make multiple flights like aircraft. We and others have studies reusable boosters and find 1) the technology is not on hand and 2) the R&D costs will be very high so there must be enough traffic to amortize the huge investment. Since this amount of traffic is not in the forecast for the next decade, we have turned to an intermediate solution, a low-cost single use booster; a later refinement of which could be recoverable upper stages carrying the more costly electronic equipment and flight subsystems.

There are two candidates for a low-cost first booster stage, the large solid propellant motor and the large simplified liquid engine, the so called "big dumb booster." Cost analyses, which are not too reliable at this state of the technology, indicate no significant cost difference. The technology for large solid motors, however, is probably farther along than for the simple liquid booster. Figure 12 shows the test record of large solid motors through last year. The Air Force program on 156 inch diameter solid motor has had nine tests and there have been three 260 inch diameter solid motor firings in the NASA program. Figure 13 shows the static test of the 260 inch SL3 solid motor in June 1967. Peak thrust was 5.9 million pounds, a world record of high thrust for a single motor, we believe. Near the end of the firing, however, there was a spectacular display resulting from ejection of burning fragments. This was caused by the improper bonding of batches of propellants during loading and is one of the problems that must be cleared up.

Another problem is lower cost nozzles, insulation, and cases through the use of different materials and techniques. Another problem requiring more attention for achieving lower cost is thrust vector control. We feel that these problems can be solved with one or two more years of technology effort and the firing of another 260 inch solid as a proof-of-concept. Concurrent with this, we are making vehicle design studies and possible missions and these indicate that a vehicle with a earth-orbit payload of about 100,000 pounds is an optimum size for a new booster. This size could be met by using a first stage consisting of either a cluster of 156 inch solid motors or a single 260 inch motor or a simple liquid propellant stage and a modified SIVB as the initial upper stage. We are examining ways that the SIVB could be simplified for this mission as, for example, removal of restart capability.

The third major need with a large impact on future aerospace activities is the use of nuclear energy for propulsion and electric power generation in space.

The phenomenal success of the nuclear rocket program, jointly conducted by the AEC and NASA, is a record of which we are very proud. Figure 14 shows the accumulated reactor and engine test time which totals 509 minutes. Last year a reactor was operated an hour at full power and numerous tests show the versatility of the system for start, restart, and variable power operation. Figure 15 is a photograph of a typical test. The time has come to make full use of this storehouse of technology by developing a flight engine. The engine, illustrated by Figure 16, would develop 75,000 pounds thrust and have a specific impulse almost double the best chemical system in use. The first logical use of the NERVA engine would be for a stage to replace the SIVB of Saturn V. It about doubles the payload and is most effective for high velocity missions such as to the planets. We are already in the design stage and we are recommending that the NERVA engine development be continued with engine and stage ready for a mission as early as 1977. We are working with other NASA offices in studying planetary and other types of missions that can use the high performance capability of a nuclear engine.

We are also working jointly with the AEC on nuclear electric power generation. Radio isotope electric power systems for low power ranges, 25 to 65 watts are already being used or planned for flight missions. The largest reactor electric generator is SNAP 8 which will generate 35 to 50 kilowatts. It is a turbomachine operating on the Rankine thermodynamic cycle, Figure 17, with three liquid metal flow loops. A sodium-potassium loop conveys heat from the reactor to a boiler where it heats mercury which drives the turboalternator.

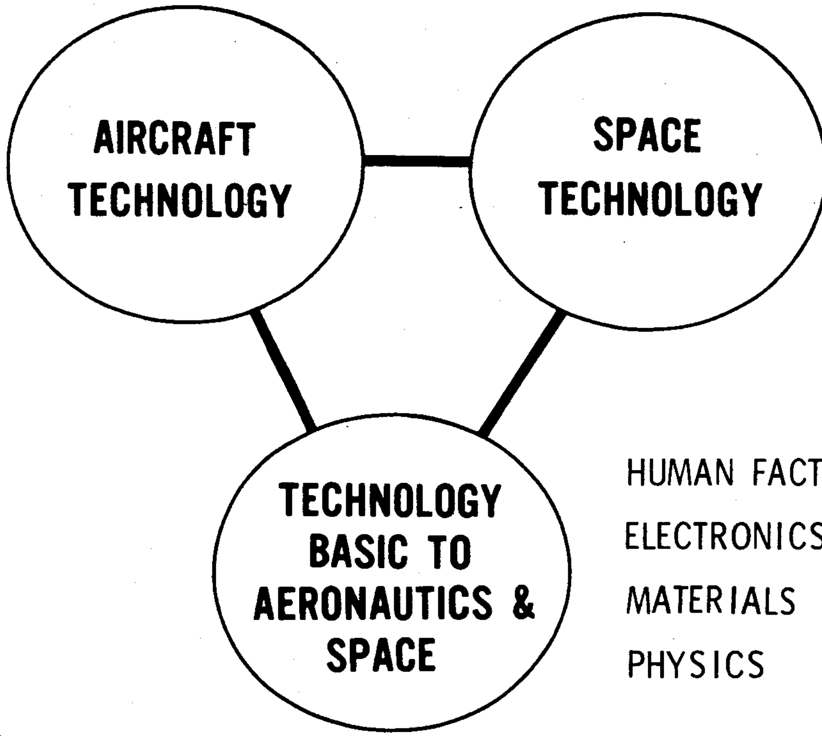
A second sodium-potassium loop removes waste heat. A fourth loop lubricates the turboalternator and pumps. The problems encountered have been formidable but we are now operating the major components in endurance tests with accumulated time of several thousand hours with a goal of 10,000 hours or better. A possible early application for such a power system would be on the lunar surface.

In summary, I have covered the role of OART in providing the enabling technology for future missions and assisting in solving current problems I have discussed three major needs-increased aircraft technology, low-cost boosters, and utilization of nuclear energy in space. I have indicated that as we move towards proof-of-concept work, industry, which already carries out the major part of our program, will become more deeply involved.

LIST OF FIGURES

ADVANCED RESEARCH & TECHNOLOGY

- SYSTEM STUDIES
- AERODYNAMICS
- STRUCTURES
- PROPULSION
- FLIGHT DYNAMICS
- OPERATING PROBLEMS



- SYSTEM STUDIES
- AEROTHERMODYNAMICS
- STRUCTURES
- PROPULSION
- SPACE POWER

HUMAN FACTORS

ELECTRONICS

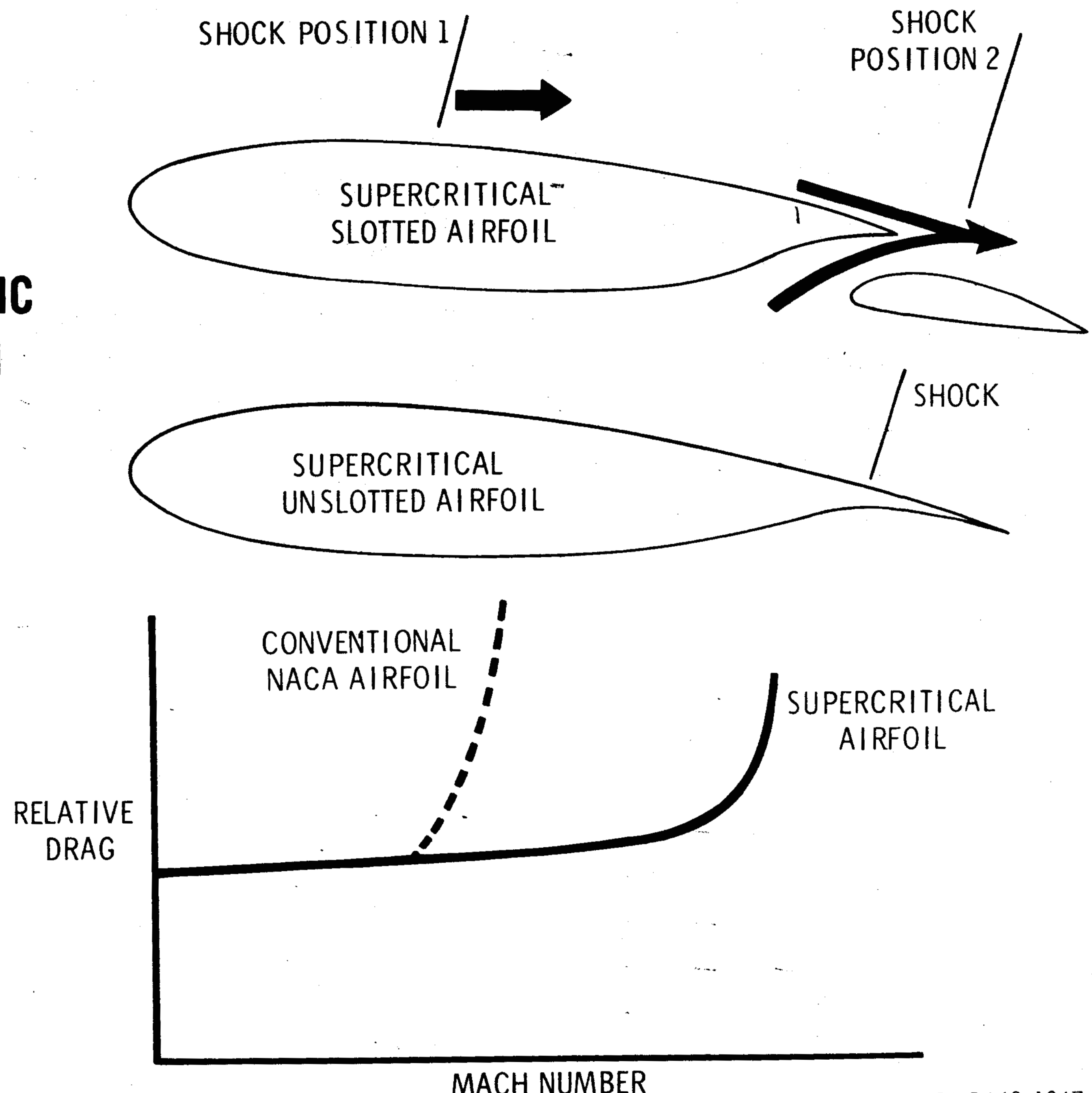
MATERIALS

PHYSICS

NASA HQ RC68-15710
12-6-67

Figure 1

AERODYNAMIC RESEARCH

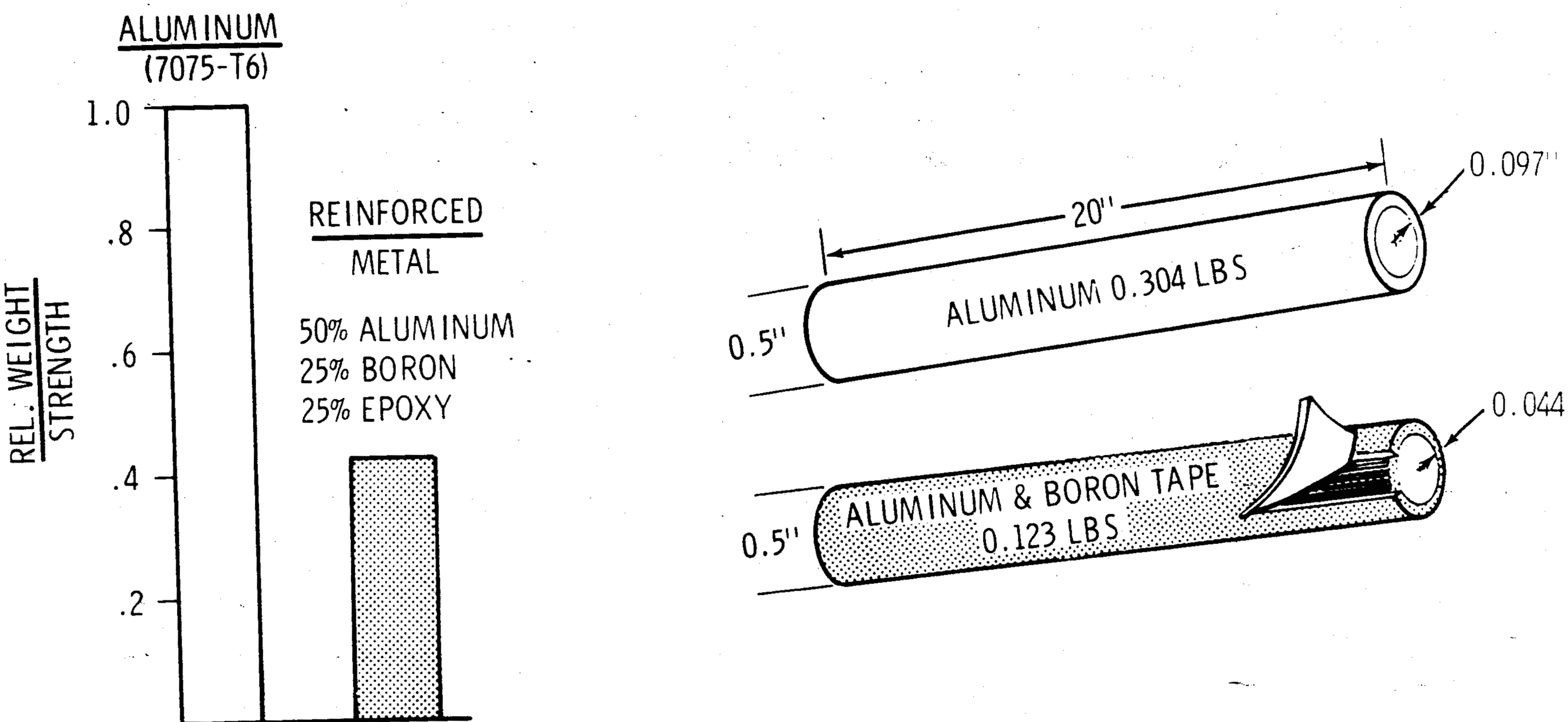


NASA RA68-1247
1-19-68

Figure 2

RELATIVE WEIGHT RATIOS

COMPRESSIVE LOAD 4700lbs

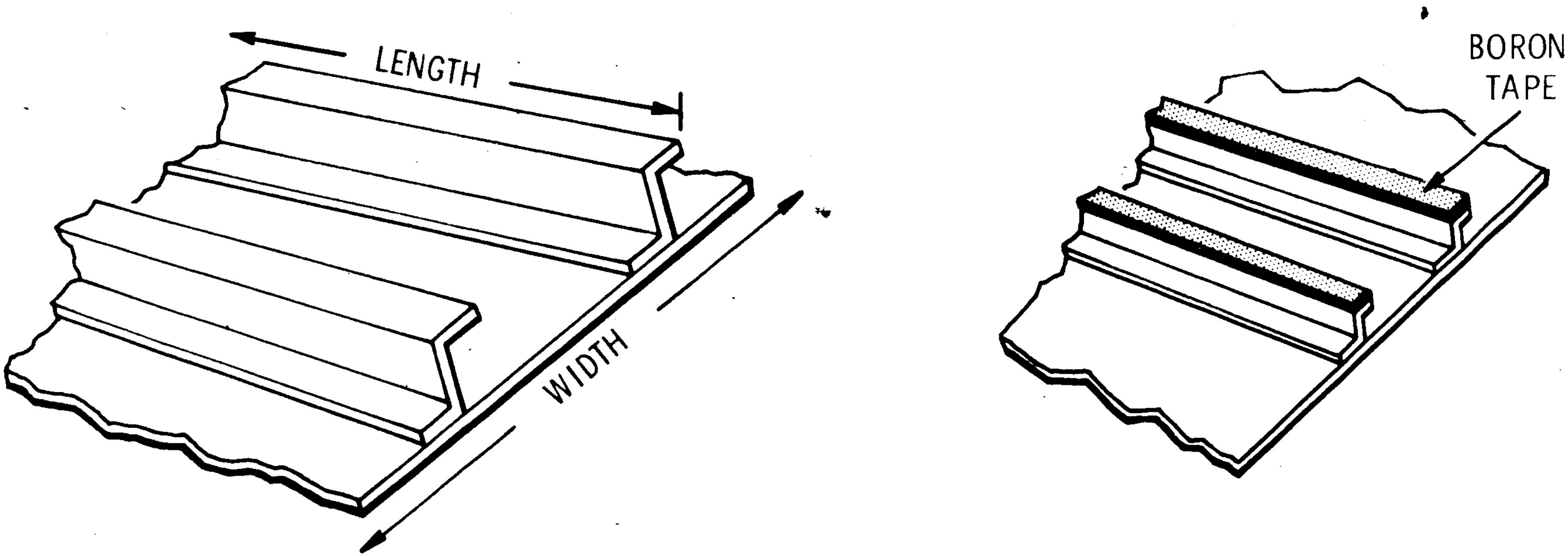


NASA RA68-1183
1-15-68

Figure 3

WEIGHT REDUCTION FOR
TYPICAL AIRCRAFT STRUCTURE

COMPRESSIVE LOAD 46000 LBS FOR 10-INCH WIDE PANEL



ALUMINUM (7075-T6)
WEIGHT – 5.69 LBS.

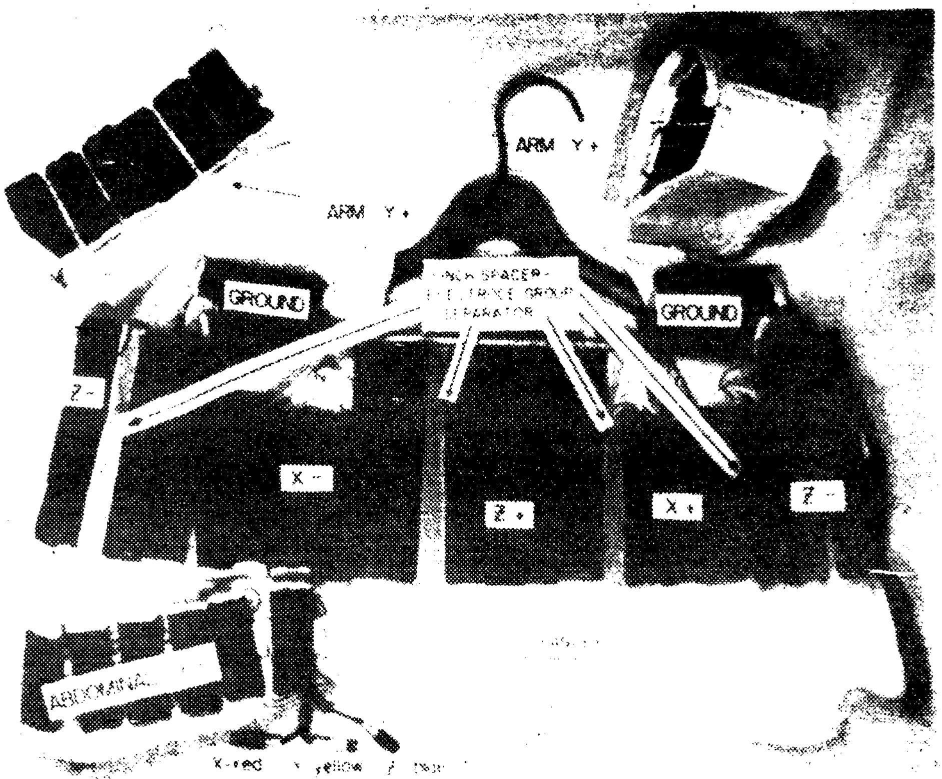
ALUMINUM & BORON TAPE
WEIGHT – 4.30 LBS.
[WEIGHT REDUCTION – 24%]

NASA RA68-1182
1-15-68

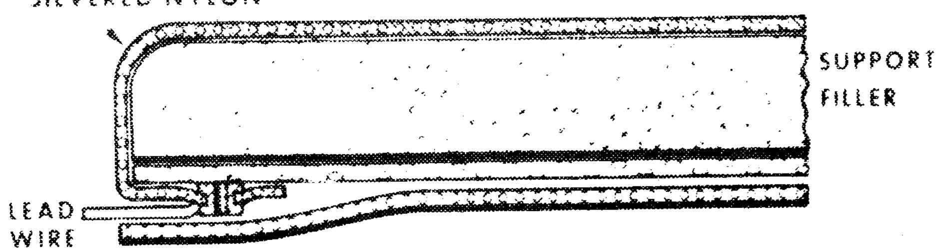
Figure 4

BIOINSTRUMENTATION

STRESS EFFECTS IN AVIATORS



DRY ELECTRODE PADS IN VEST

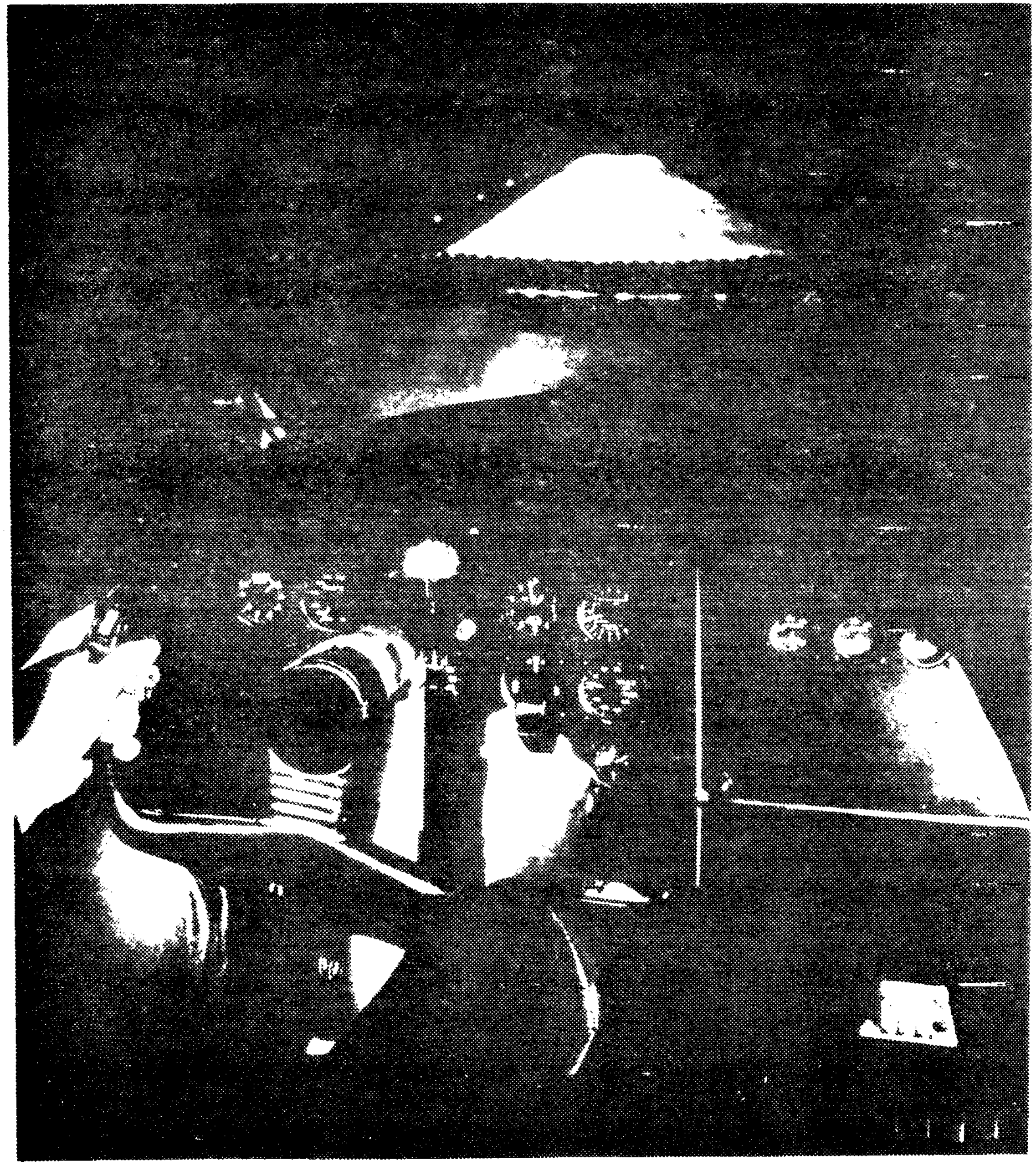


CROSS SECTION

FLIGHT RESEARCH CENTER

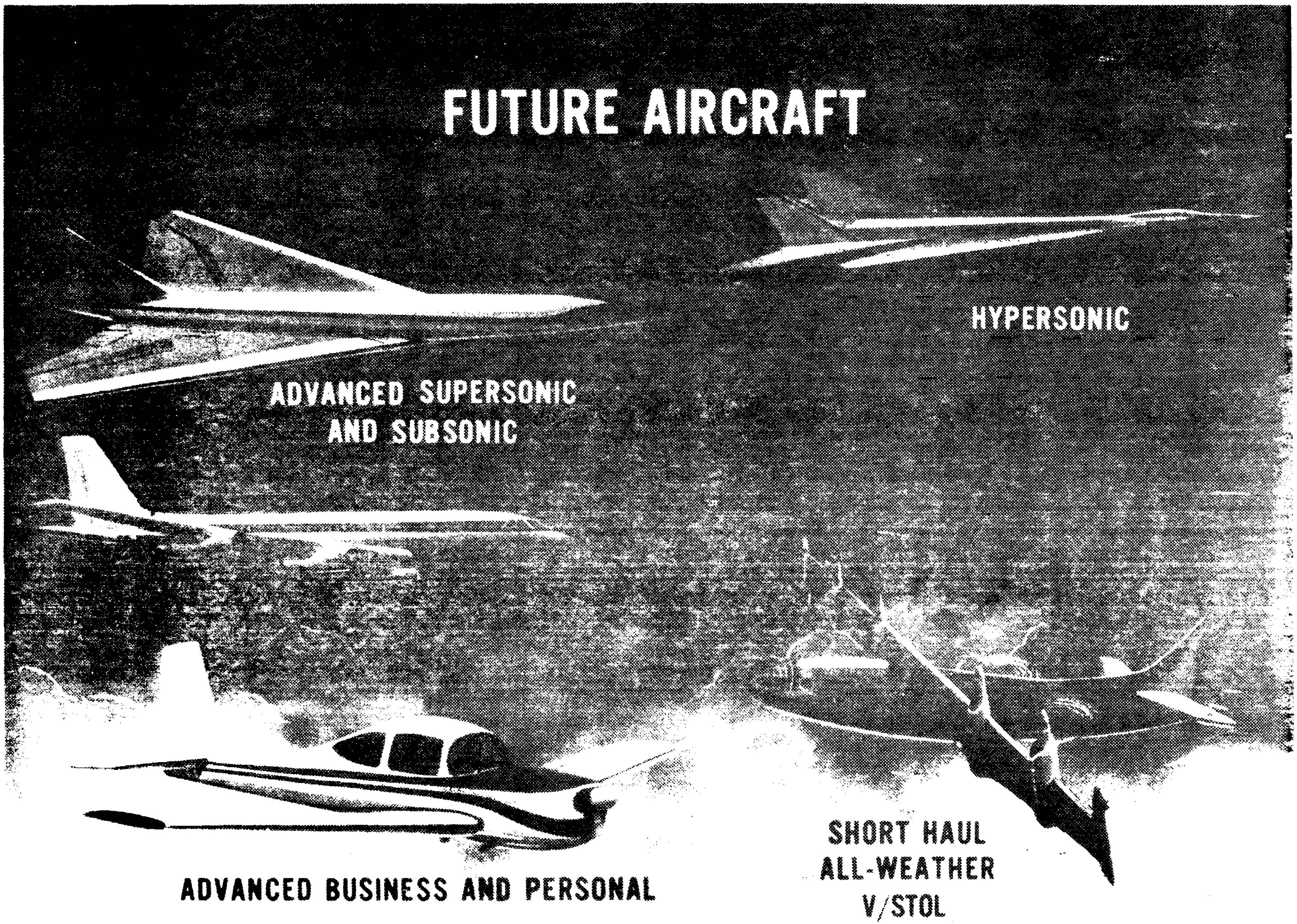
Figure 5

PLANNED AIR CREW WORKLOAD RESEARCH



AMES RESEARCH CENTER

Figure 6



NASA R 67-1343
12-28-66

Figure 7

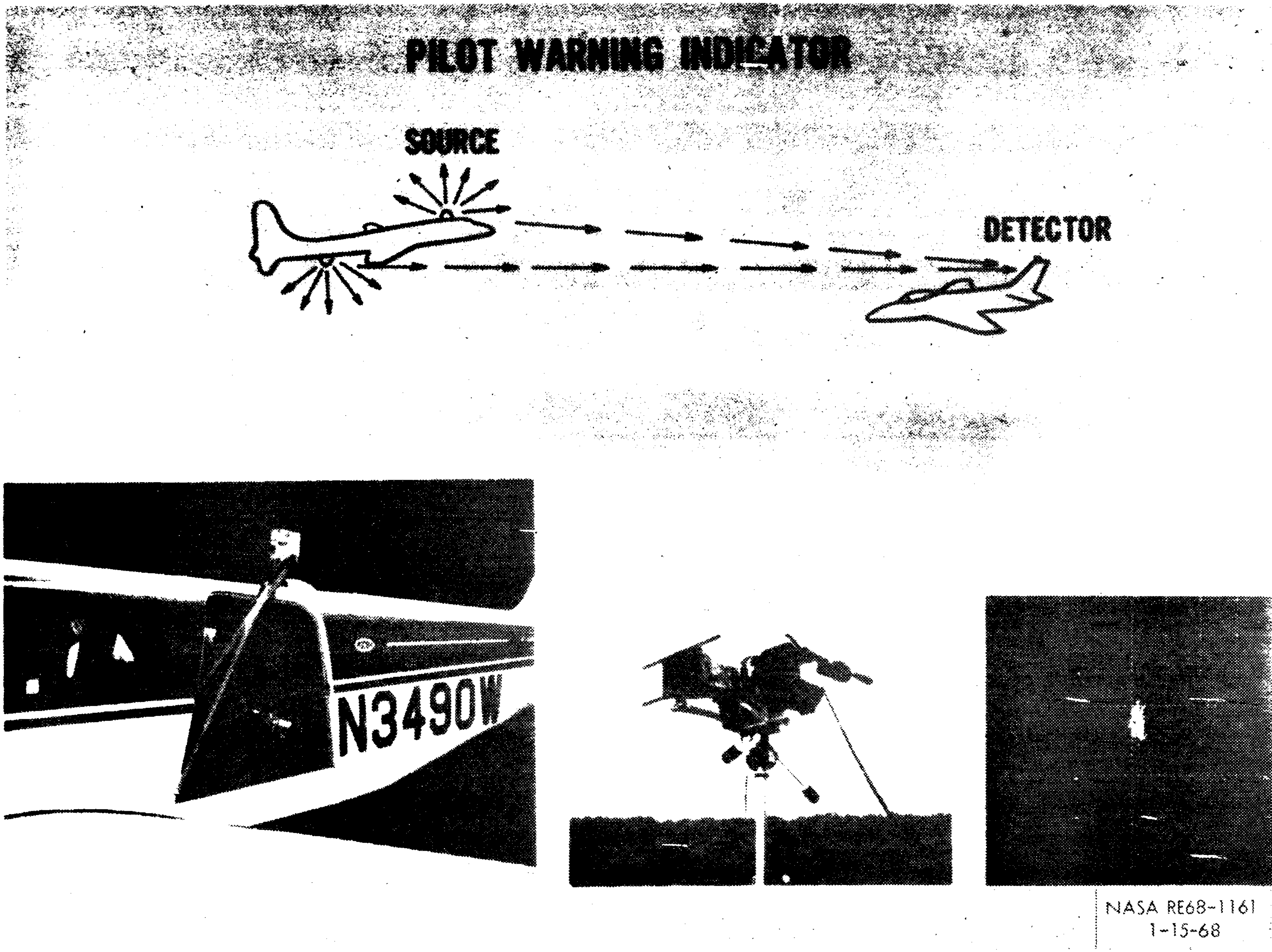

PILOT WARNING INDICATOR
SOURCE
DETECTOR
N3490W
NASA RE68-1161
1-15-68

Figure 8

TYPICAL VTOL PERFORMANCE

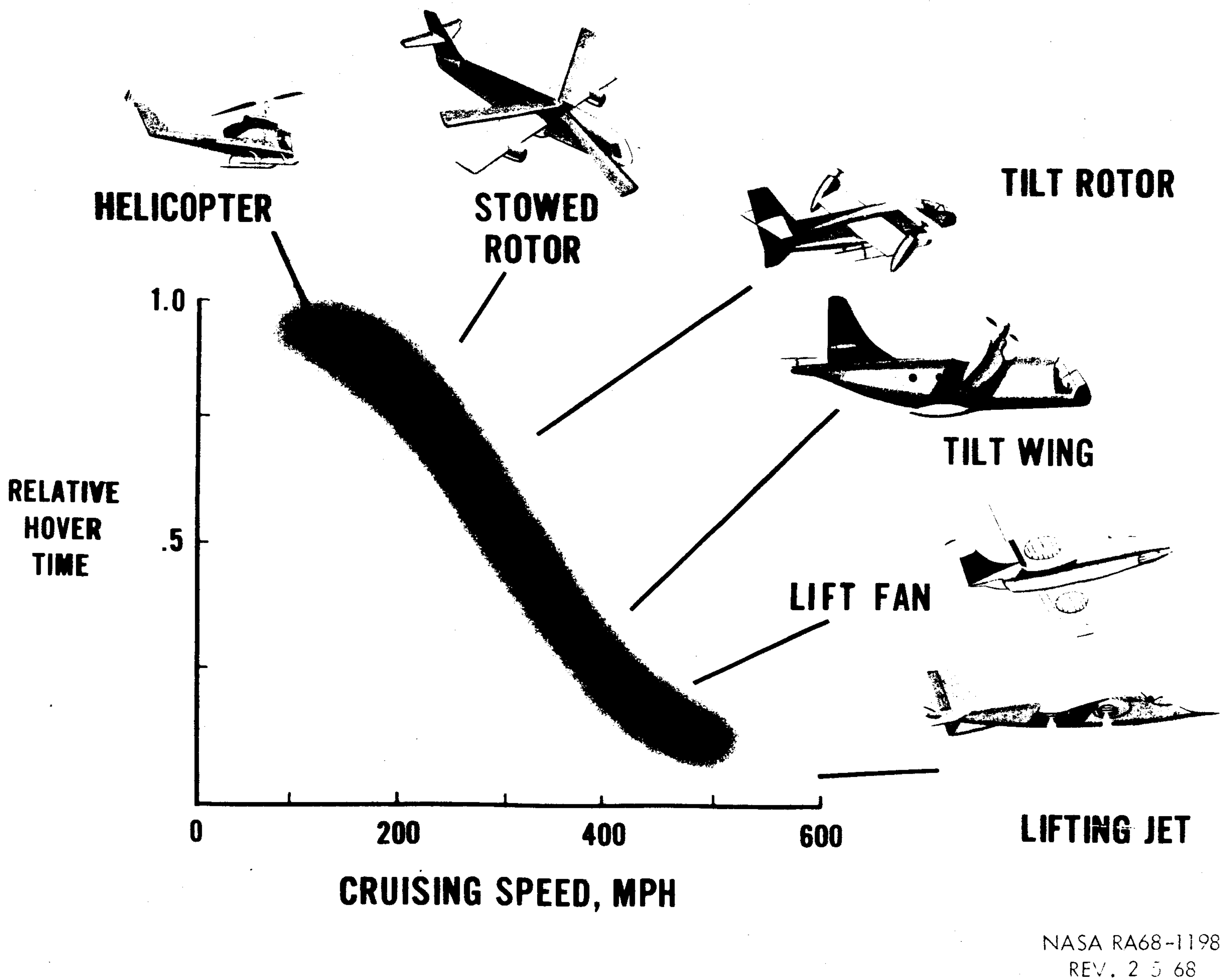
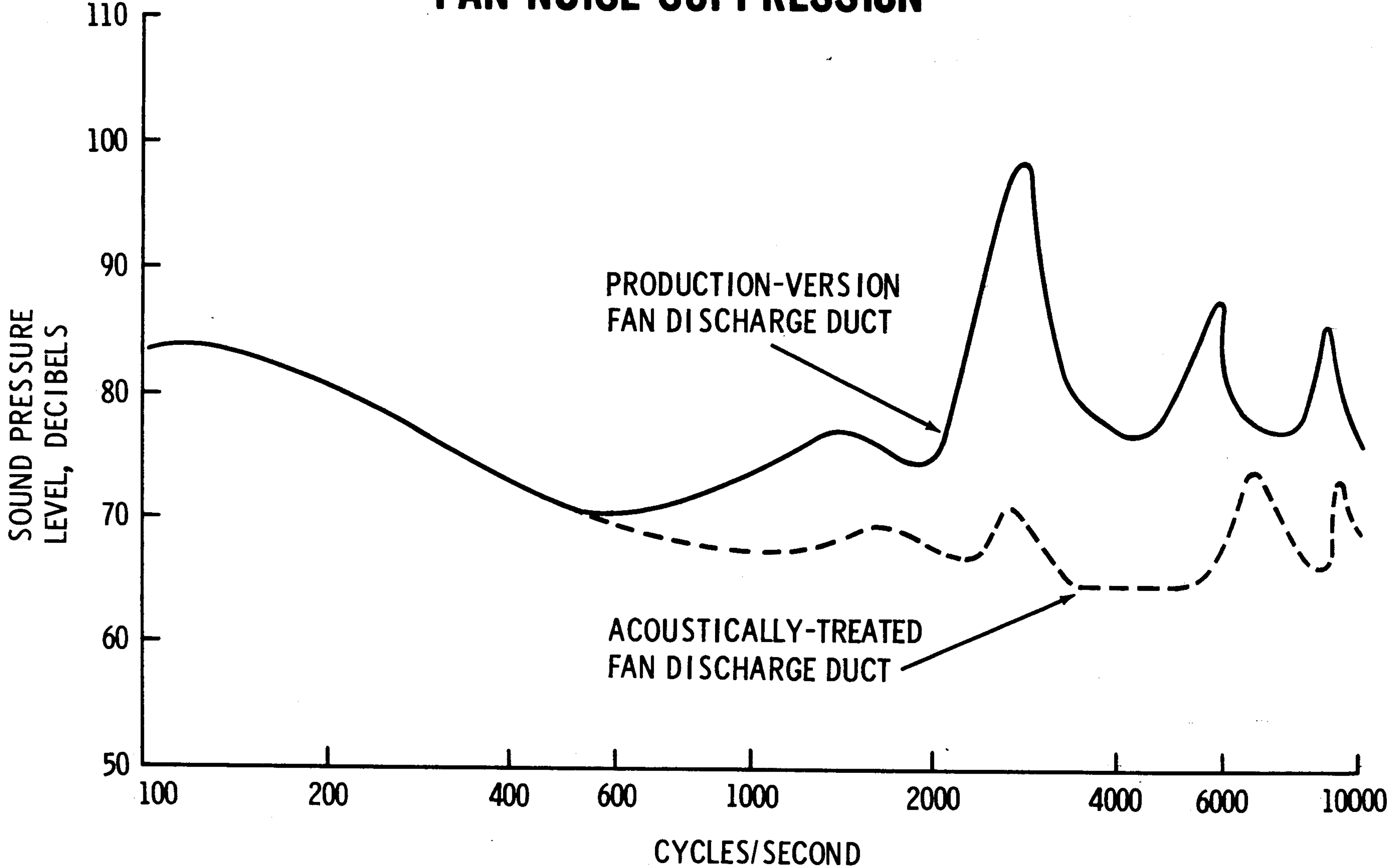


Figure 9

FAN-NOISE SUPPRESSION



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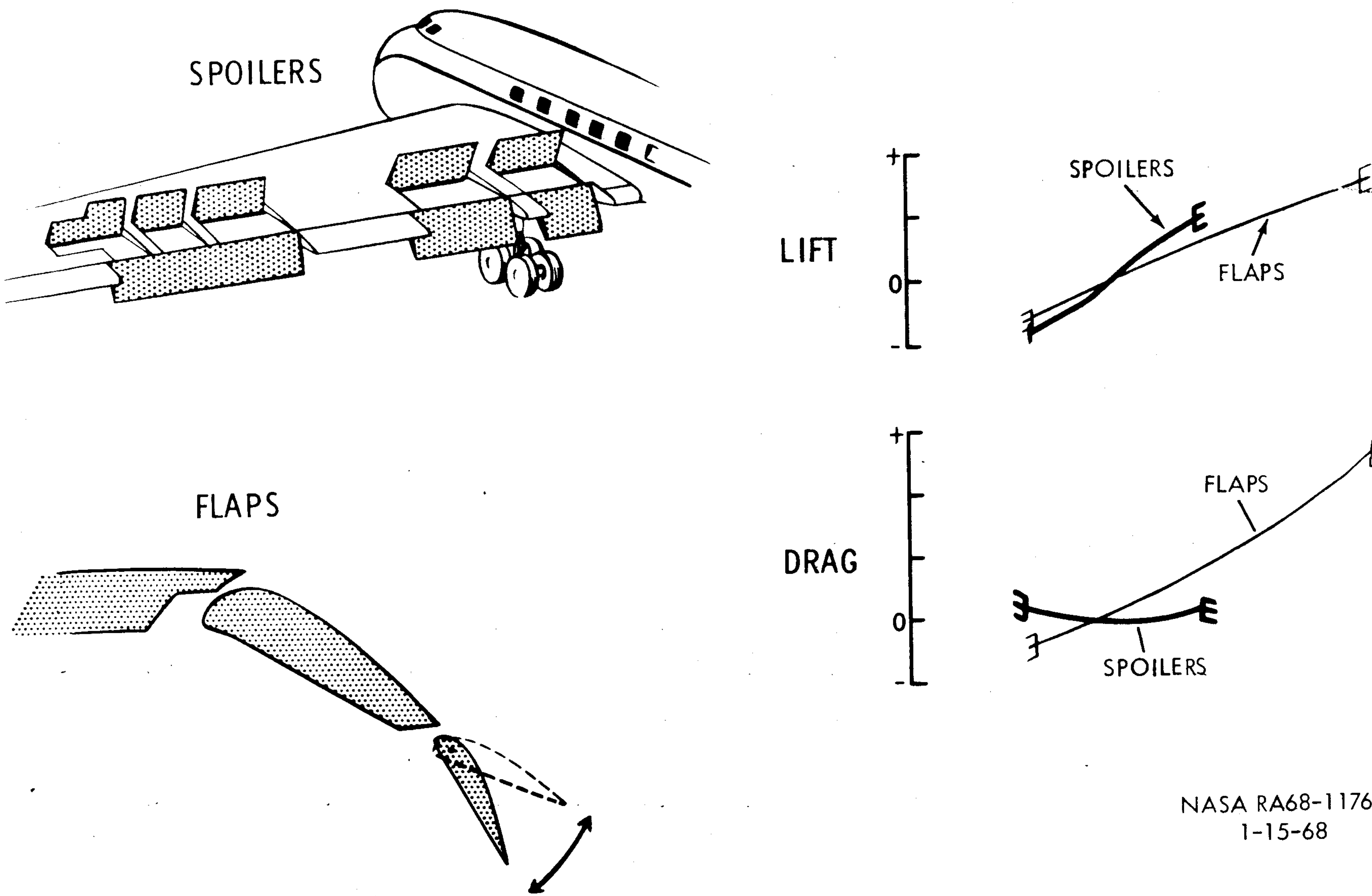
1-15-68

Figure 10

DIRECT LIFT CONTROL DEVICES



NASA RA68-1176
1-15-68

Figure 11

LARGE SOLID MOTOR TEST RECORD

MOTOR DESIGNATION	TEST DATE	PROP WGT (10^6 LB)	MAX THRUST (10^6 LB)	BURN TIME (SEC)	TVC TEST	COMPANY
156–1	5–64	0.42	0.9	108	JET TABS	LOCKHEED
156–2	9–64	0.63	1.1	143	JET TABS	LOCKHEED
156–3	12–64	0.69	1.4	126	GIMBAL	THIOKOL
156–4	2–65	0.80	3.3	59	NONE	THIOKOL
156–5	12–65	0.69	3.1	55	LIQUID INJ	LOCKHEED
156–6	1–66	0.27	1.0	65	LIQUID INJ	LOCKHEED
156–HG	4–66	0.16	0.3	122	HOT GAS INJ	LOCKHEED
156–7	5–66	0.13	0.4	110	LIQUID INJ	THIOKOL
156–9	5–67	.27	1.0	77	FLEX BEARING	THIOKOL
260, SL–1	9–65	1.7	3.6	114	NONE	AEROJET
260, SL–2	2–66	1.7	3.6	114	NONE	AEROJET
260, SL–3	6–67	1.7	5.9	70	NOZZLE STRUCTURE ONLY	AEROJET

DAC DATA

NASA HQ RP67-17073
Rev. 1-25-68

Figure 12

STATIC TEST OF SL-3 SOLID MOTOR

JUNE 17, 1967

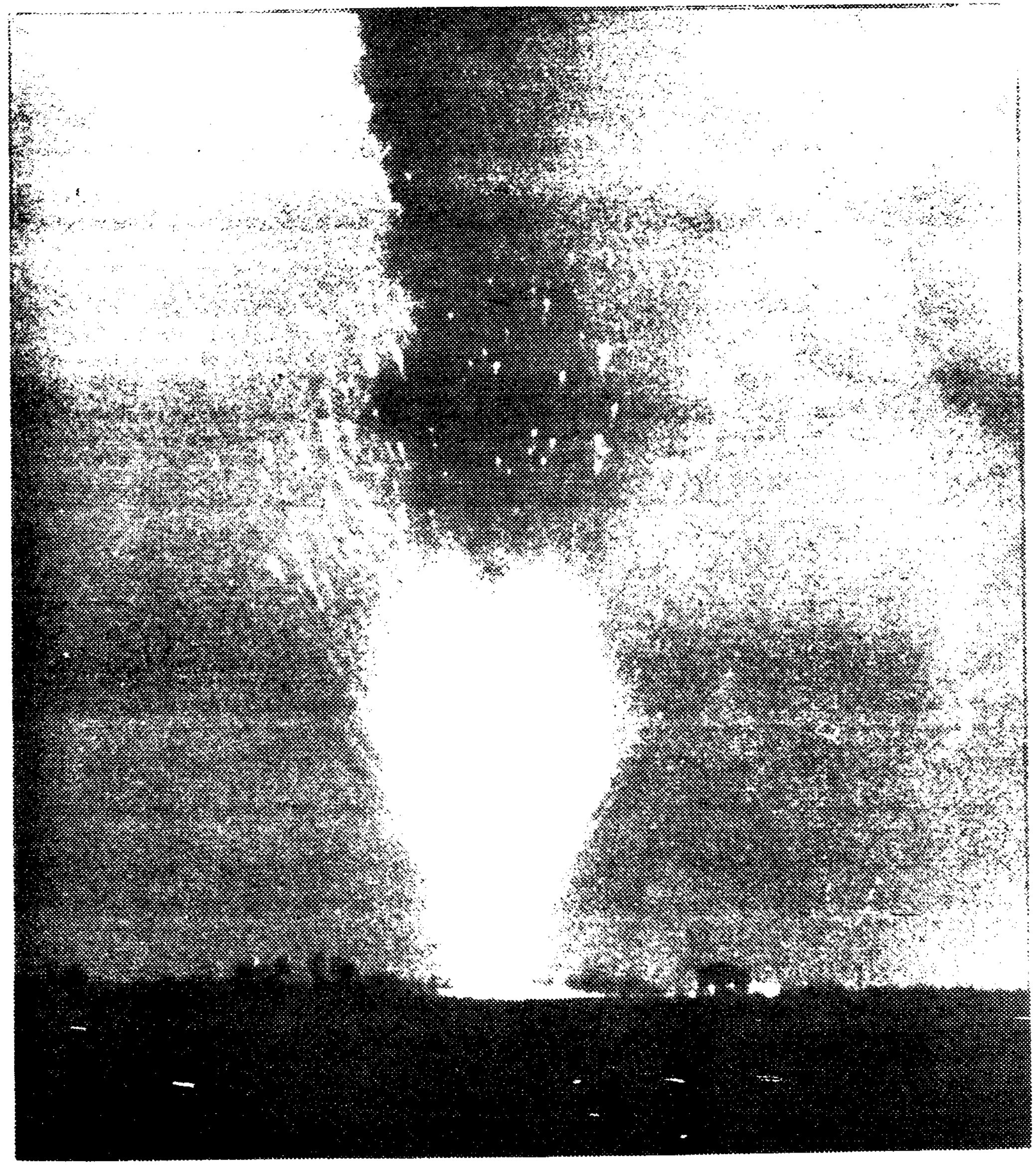
PEAK THRUST — 5.9M POUNDS

THROAT DIAMETER—89 INCHES

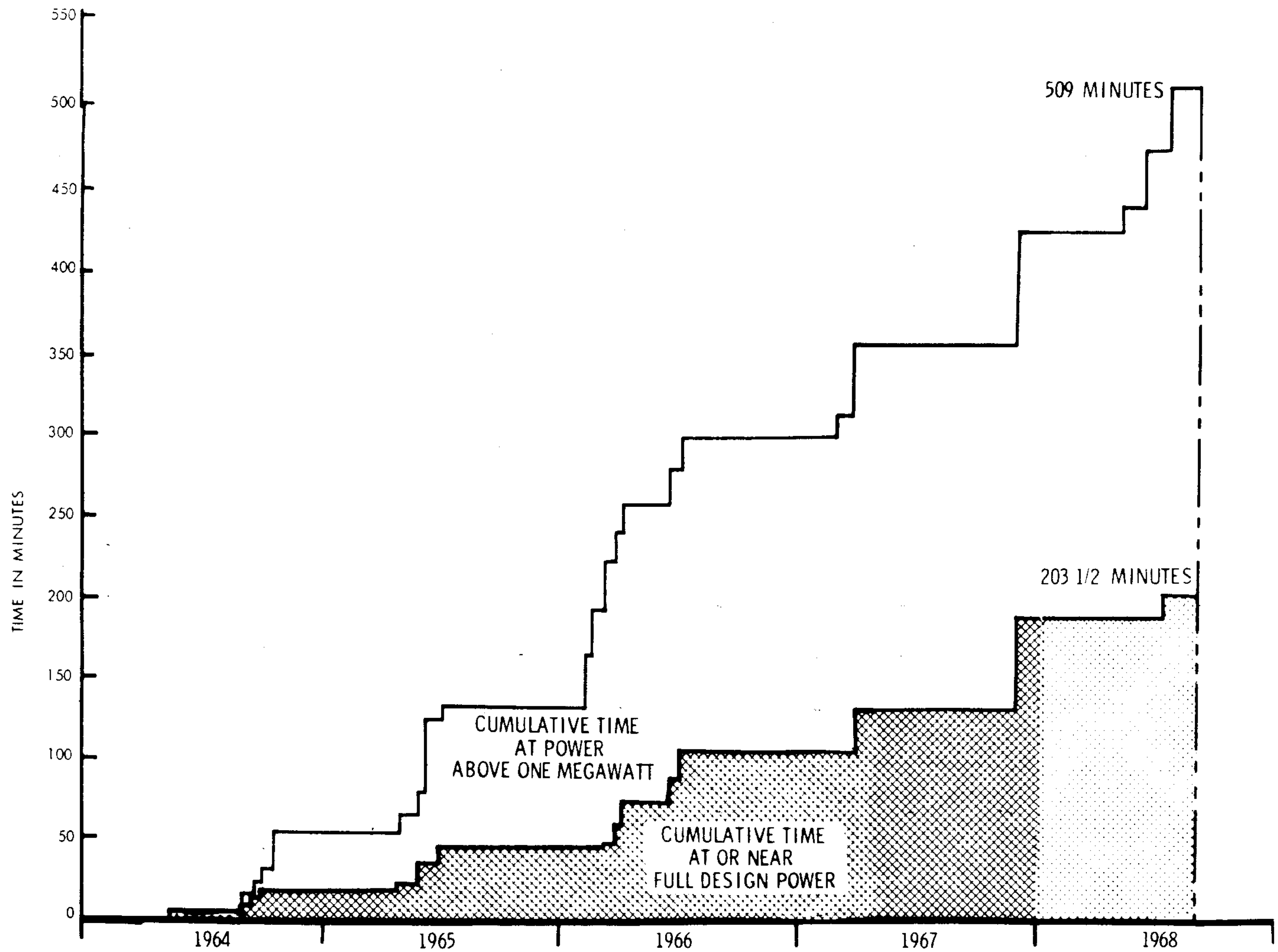
WEIGHT —— 1.7M POUNDS

NASA HQ RP67-17040

Rev. 1-25-68



REACTOR AND ENGINE SYSTEM CUMULATIVE TEST TIME 1964-1968



NASA NPO67-1569
Rev. 10-30-68

Figure 14

NASA HQ RC68-15828 1-8-68

Figure 15

NERVA ENGINE

- **THRUST, LB.**
  APPROXIMATELY 75,000
- **SPECIFIC IMPULSE, SEC.**
  825
- **CHAMBER TEMPERATURE, °R**
  4,500
- **PROPELLANT FLOW RATE, LB/SEC.**
  90

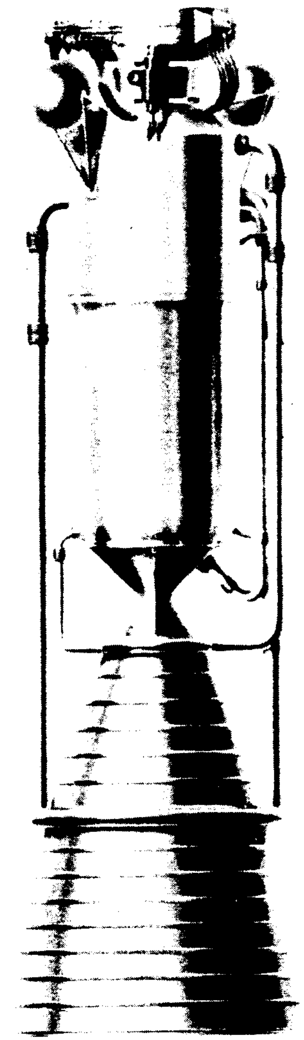


Figure 16

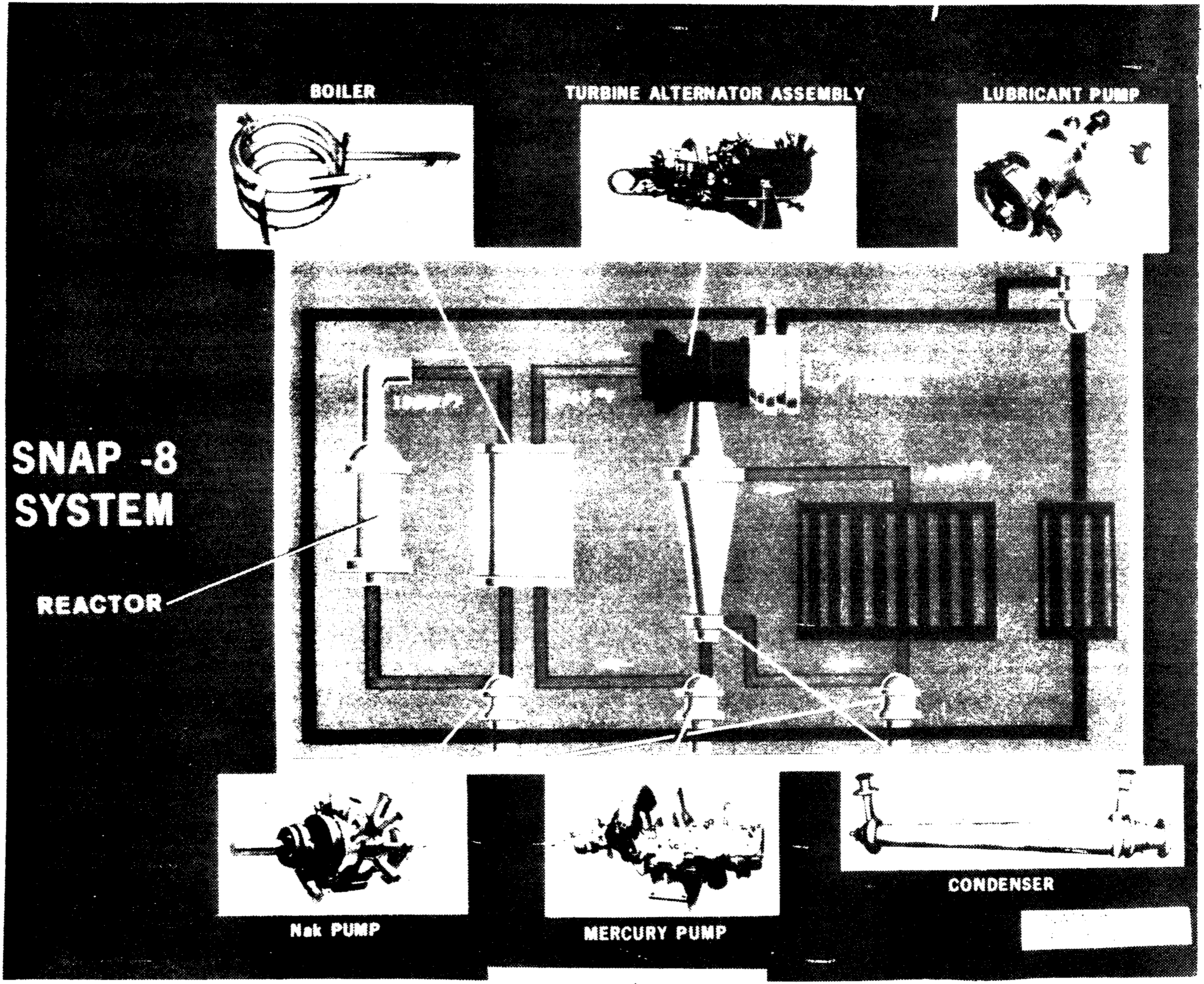

BOILER
TURBINE ALTERNATOR ASSEMBLY
LUBRICANT PUMP
SNAP -8
SYSTEM
REACTOR
Nak PUMP
MERCURY PUMP
CONDENSER

Figure 17